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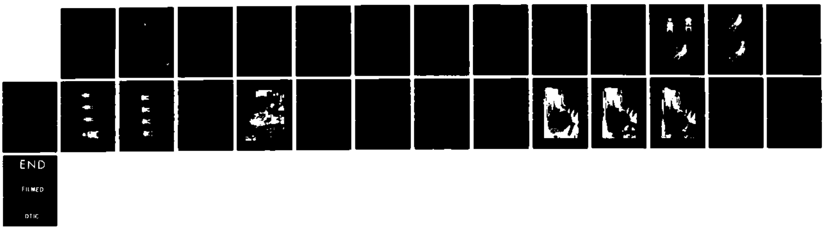

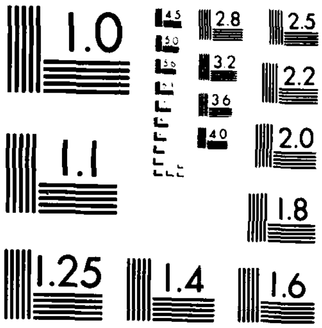

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A SAFETY EVALUATION OF THE RELOCATION OF THE ACM PANEL IN THE F-14 ( )/AIP

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Aircraft and Crew Systems Technology Directorate (Code 6032)

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Ejection Safety

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A goal of the F-14( ) Avionics Integration Program (AIP) is to increase the field-of-view of the pilot's Head-up Display (HUD). One way to accomplish this would be to move the HUD closer to the pilot. However, if this were done, the Air Combat Maneuvering Panel (ACM), which is located on the face of the HUD housing, would either intrude, by approximately 1.25 inches, into the ejection envelope or the ACM panel functions would have to be redistributed throughout the F-14 cockpit. A computer simulation of ejection clearance was performed using a digitized representation of the F-14 cockpit with the relocated HUD. This study was complemented by three live

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20.

subject ejection tower tests using a foam board representation of the revised ACM panel position. Both the analytical study and the tower tests indicate that the relocation of the ACM panel poses little risk of causing interference during ejection. However, extensive testing, using optimum fidelity seat performance and simulated cockpit structure, would be required to qualify the revised configuration if this option were to be implemented.

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BACKGROUND

One of the objectives of the current F-14 Avionics Integration Program, which is being conducted by the Grumman Aerospace Corporation, is to improve the pilot's field-of-view through the Head-up Display (HUD). One way to accomplish this is by bringing the HUD closer to the pilot. However, since the Air Combat Maneuver (ACM) panel in the current configuration is mounted in front of the HUD housing, it would also have to move closer to the pilot. This could create a problem since the relocated ACM panel would then intrude into the current ejection envelope by as much as 1.25 inches. To avoid this, the ACM panel functions could be broken up and relocated to various other positions within the cockpit. However, this could negate the current optimum positioning of these functions with respect to the pilot and would call for additional crew station redesign to accommodate the relocated components of the ACM panel. During informal discussions with Grumman engineers, the NAVAIRDEVCEN became aware that a determination of the impact of allowing the ACM panel to intrude into the current ejection envelope would be of significant value in helping define the degrees of freedom available to the F-14 (   ) AIP crew station designers. After consultation with the NAVAIRDEVCEN F-14 Program Office and NAVAIR, the Seating and Escape Branch (Code 6032) of the Life Support Engineering Division, Aircraft and Crew Systems Technology Directorate received authorization, under Airtask Number A542541D/001D/301408000, to conduct a study.

The purpose of this study was to consider the potential impact on ejection safety by allowing the relocated ACM panel to intrude 1.25 inches into the ejection clearance envelope. The 1.25 inch intrusion was not intended to represent any specific configuration. Rather, it was used to represent the boundary of a "space" that could be used to increase the number of potential alternative design solutions available to the Grumman crew station engineers.

This study was conducted in two parts. First, a mathematical model of the cockpit geometry was developed and a computer simulation of the ejection clearances with respect to the ACM panel relocation was run. Secondly, a series of three ejection tower tests were conducted on the NADC ejection tower using a styrofoam mockup of the ACM panel and human test subjects. Both portions of this study were run as part of a joint effort by the Navy and Grumman to improve the pilot's field-of-view through the HUD while minimizing any changes to the crew station.

The study began by mathematically modeling the F-14 crew station with a 95th percentile seat occupant. Simulations were conducted with the occupant under a flat spin environment, and under a zero G field. Three ejection tower tests were then conducted using three different subjects on an F-18 SJU-5/A ejection seat with the rudder pedals and ACM panel located as in an F-14. The tower test represent ejection in the "O" G field and were used to verify the simulation results.

CONCLUSION

It appears feasible to include the relocation of the ACM panel into the ejection clearance envelope by up to 1.25 inches among the options for enhancing the F-14 (   )/AIP field-of-view. However, further studies, using test configurations more closely duplicating the F-14 cockpit environment and using a greater range of test subjects, would be needed to fully qualify the reduction in ejection clearance envelope.

RECOMMENDATIONS

The following are recommended:

1. Conduct a static ejection path clearance study on an F-14 aircraft to verify ejection clearances and cockpit ingress/egress.

2. Evaluate the human factors implications associated with relocating the ACM/HUD to ensure non-interference with other crew station functions.

3. Verify these preliminary results with further ejection tower tests, utilizing an F-14 GRU-7 ejection seat equipped with lower leg restraint and a broader range of test subjects.

MATHEMATICAL MODELING STUDY

The computer simulation of the anticipated response of the F-14(   )/AIP pilot trajectories of the lower leg, and the foot in particular employed previously described methodologies and data sets. A brief description of the various areas considered follows.

CREW STATION GEOMETRY

The Cockpit Geometry Evaluation Computer Program System was used to check and transform digitized crew station data describing the F-14(   )/AIP. In this application of the program, two reference systems were used. The first was the Aircraft Design Coordinate System, where the surface vertices and control locations were expressed using crew station drawings (drawing ≠A51F00205 - Grumman Aircraft Engineering Corporation.) The data were then transformed to a euclidean coordinate system (x,y,z) with its orgin at the Design Eye Reference Point. The crew member anthropometry and seating position was used to define seat pan location, which was then checked against the allowable seat adjustment range. Occupant pre-ejection position constituted the orientation of feet symmetrically in contact with the rudder pedals, hands on the seat pan "D" ring, and head pushed up against the head box (see Figure 1).

OCCUPANT MOTION SIMULATION

The "Bioman" program routinely used to simulate occupant response has been described in detail in a previous publication[1]. This model is quite flexible and modular in design so that the complete range of anthropometric variations, weight distribution, moment of inertia of segments, and joint limiting angles can be handled efi_ctively. The occupant can be modeled by up to twenty segments, connected by nineteen joints. The complete flexibility in anthropometric dimensioning, together with the ability of specifying omnidirectional input and dynamic initial conditions, make this program an ideal tool for evaluating the occupant – crew station compatibility under acceleration. Segment-segment and segment-crew station contacts are also monitored and evaluated in terms of forces generated.

ANTHROPOMETRY

Options for different graphic representations of the human body are provided by the Bioman model. Which model should be used is determined by the complexity of analysis desired and the likelihood of physical interference occurring. The program provides optional output of segment time histories and contact ellipsoid information. Each segment is modeled via an ellipsoid, whose origin (in relation to the segment center of gravity location) and force deformation properties are specified. Use of this package greatly facilitates interpretation of data, and it can be used as a preprocessor to isolate specific crew station surfaces with which contact might occur (Figure 2).

To increase the resolution by attaining a better facsimile of the human form, a refinement of anthropometric representation was undertaken based on Biosteriometrics by which the entire skeletal structure, or portions thereof, can be driven under computer control (Figure 1). As was the case in the elliptical link representation, it is a relatively simple task to dimension the data to represent various anthropometric categories. Changes in link lengths, keeping the number of slices the same, will result in the spacing between each successive slice being increased, and vice versa. Increasing or decreasing the contour of the slices themslelves is accomplished by defining a vector extending from the center of gravity of a slice to each point constituting the outline. Upward or downward scalings of the vector lengths is used to redefine the location of these outline points.

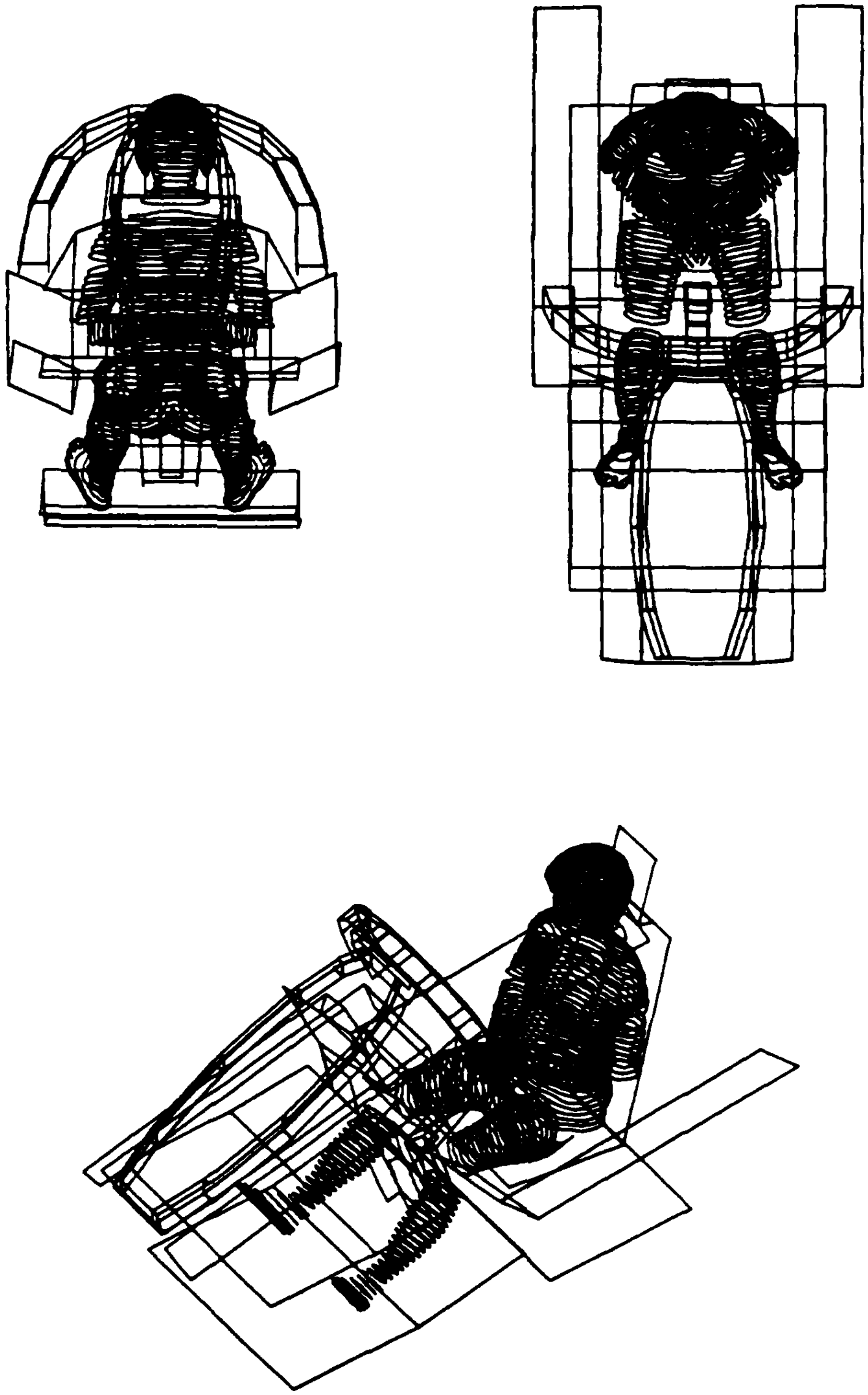

Figure 1. Occupant Seated at Design Eye Point

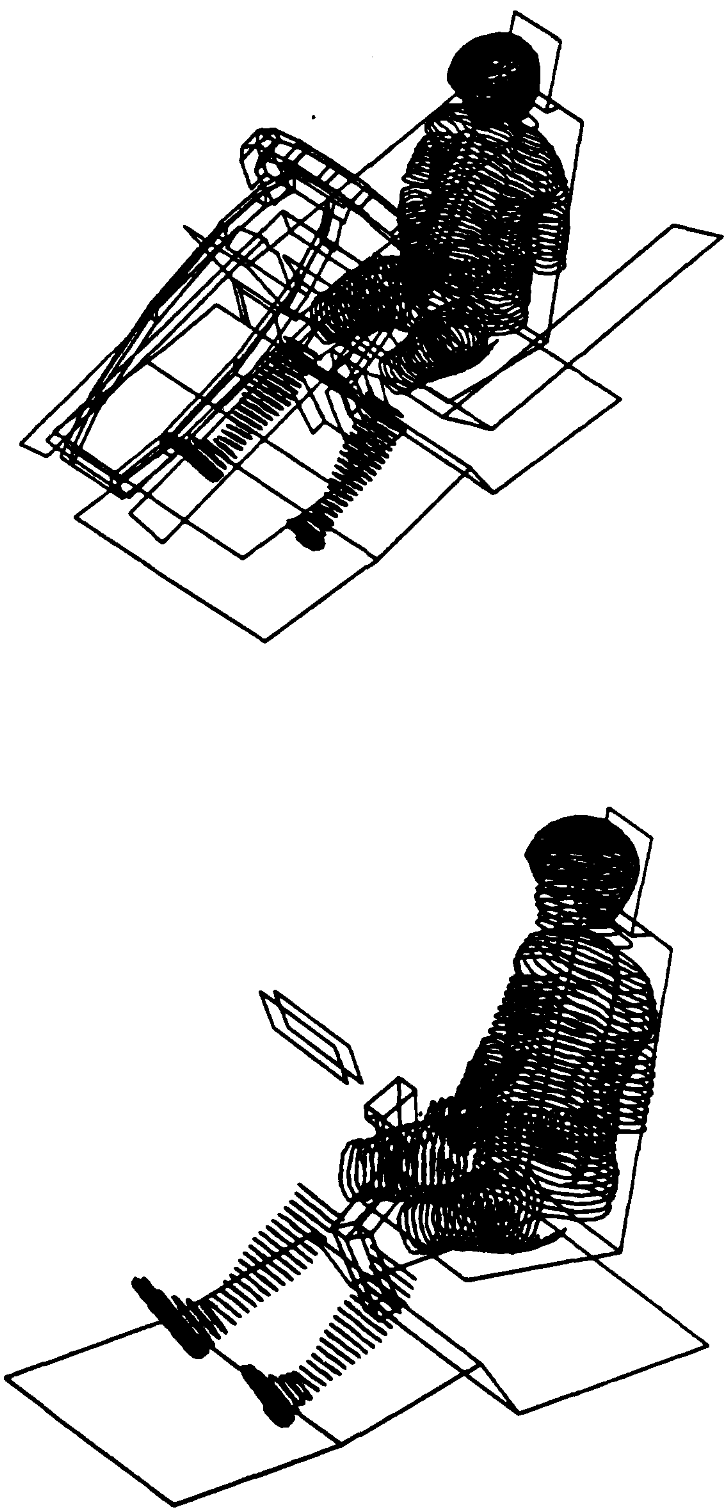

Figure 2. 98th Percentile Occupant Seated in Optimum Position

BIODYNAMIC SIMULATION

Previous simulations and validating track and tower tests have been used to establish a standardized occupant configuration that has been effectively used to conduct comparative analysis between a variety of crew stations of which the F-14 was one example[1]. In order to conduct a relative assessment, identical anthropometry must be considered. In other words, given a subject, what would his leg and foot orientation look like in the various crew stations.

The 95th percentile seated knee height and upper leg length (Buttock-popliteal/seated) were used to estimate the leg link lengths. This "straight percentile" definition overestimates the 95th percentile by length but does give conservative results. Since long legs have a higher probability of strikes, one would rather assume hits when none would actually be experienced than to predict no hits when they might in fact exist. From the rudder pedal locations (neutral full forward) and the foot dimensions modeled, the ankle location in the aircraft can be calculated using the heel rest line. Similarly, the hip location can be defined relative to the Seat Reference Point with the seat in the full down position. The three-dimensional location of the hips and the ankles, together with the stipulated leg link lengths, determine the angular orientation of the upper and lower leg and the resulting knee location in the aircraft (Figure 2). For this particular simulation, the forward relocation of the instrument panel is shown in the bottom portion of Figure 2, where all contact surfaces, save the seat, floor, control stick and old and new instrument panels have been stripped away.

Two separate and distinct ejection simulations were conducted to evaluate the revised position of the ACM panel, one under deceleration, representing a flat spin, and another under normal conditions with the revised instrument panel intruding into the ejection clearance envelope. As anticipated, under crew station $-G_x$ deceleration, the lower leg response is affected and the feet do not swing back at a fast enough rate to clear the lower portions of the instrument panel (Figure 3). Since foot contact occurs early in this particular simulation, subsequent foot-instrument panel interaction cannot easily be quantified for the latter portions of the ejection, especially under a constant decelerative force. It is indicated that the feet will be scraped along the remaining instrument panels and further simulation seems to be unwarranted.

Under normal ejection conditions, the results are clearly quite different. Figures 4 and 5 show front and top views of the ejection and corresponding foot trajectories. It will be noted that the feet clear the revised instrument panel even though it intrudes into the ejection clearance envelope. This is because the panel is high enough in the crew station to allow the lower leg and foot to swing back and align themselves with the ejection vector. It should be noted, however, that the simulation considered the GRU-7 seat configuration, with the occupant perfectly restrained. It did not consider interaction between the lower legs and seat sides, which have been occasionally noted on ejection tower tests employing human subjects. If such interaction occurs, the aft motion of the lower leg and foot could be retarded. Consequently, the results noted can be viewed as the best case situation. This facet of the simulation could not be assessed or verified from the conducted ejection tower tests, since an F-18 seat was employed in conjunction with the F-14 crew station mock-up. The human test results did confirm, however, the simulation conclusions.

EJECTION TOWER TEST PROGRAM

Ejection tower tests using human test subjects is one of the most effective ways of verifying cockpit ejection clearances. Three tests were performed with volunteer tests subjects to observe their lower leg and foot travel past the mock-up ACM panel. These three tests were "piggy-backed" to a series of tower tests already underway as part of the physiological acceptability tests for the

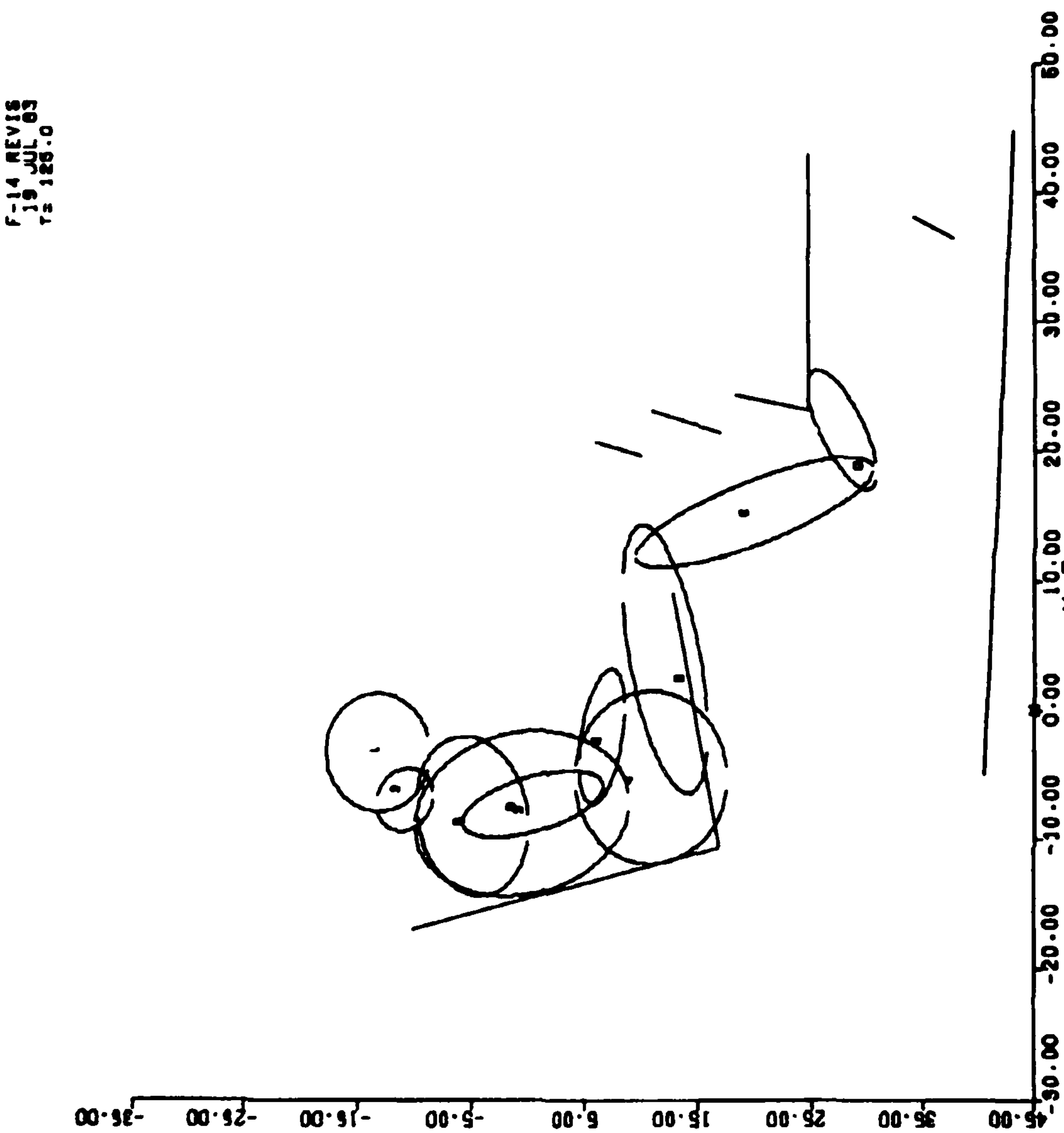

Figure 3. Foot-Instrument Panel Contact Under-G_x Deceleration

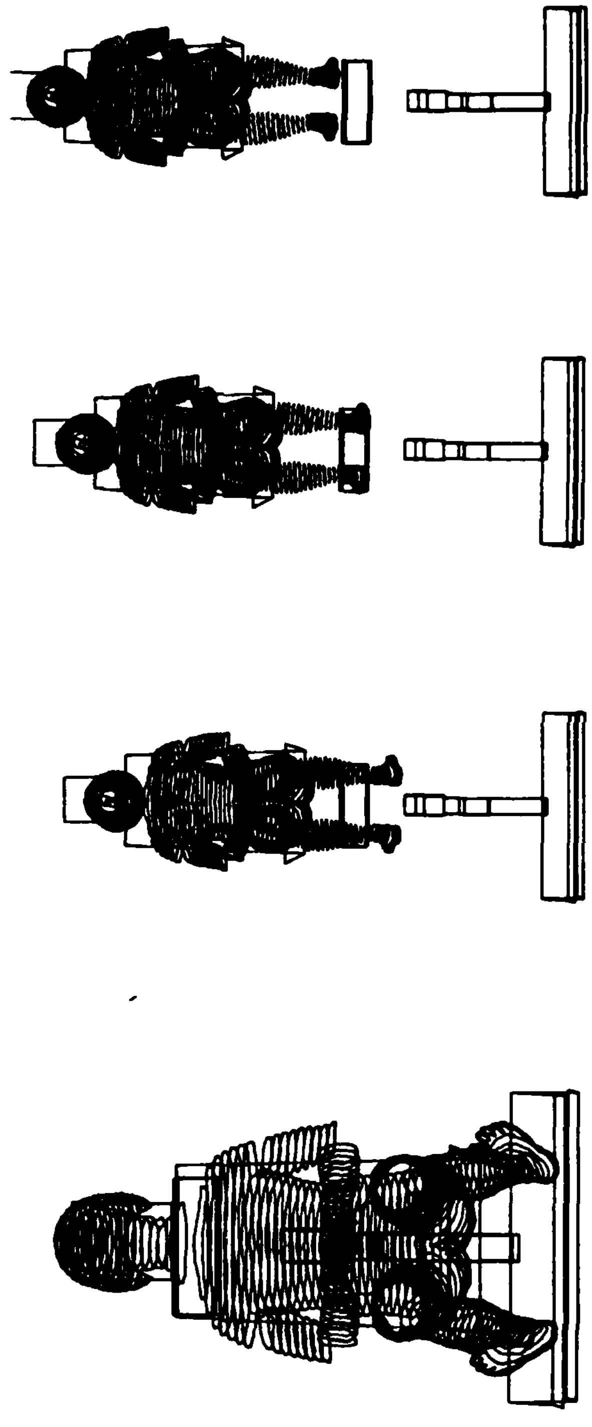

Figure 4. Front View of Ejection from F-14 with Relocated ACM Panel

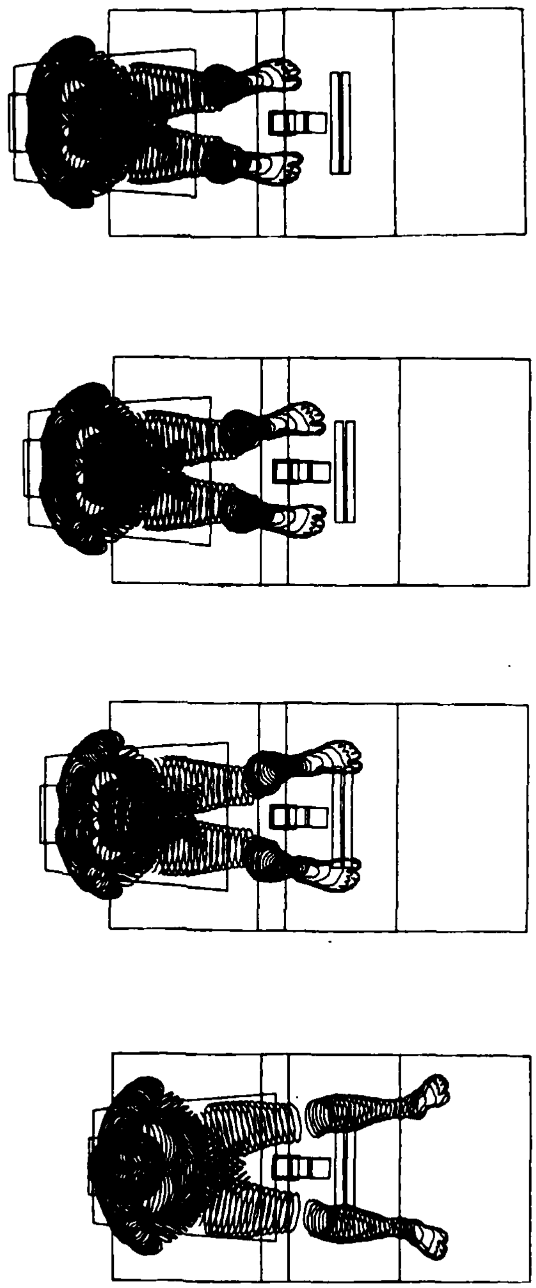

Figure 5. Top View of Ejection from F-14 with Both ACM Panel Locations

F-18 escape system update program (Ref. 2). It should be stressed that this study is not intended to be a qualification test series for the relocated HUD/ACM panel but only a feasibility study.

TEST ITEM DESCRIPTION

EJECTION TOWER

All tests were conducted at the NAVAIRDEVCEN Ejection Seat Tower Facility. The ejection seat tower is a 150 ft. structure inclined and supported at an angle of 20 degrees, 50 minutes from the vertical. It is capable of accepting current ejection seats. By controlling the cartridge propellant weight and the internal volume of the catapult, a selection of seat accelerations between 4 and 30 G can be produced. Being man-rated, the tower is an important tool in determining the physiological acceptability of escape system acceleration forces using human volunteer subjects.

AIRCREW STATION MOCK-UP (PILOT)

A cockpit floor was constructed and adjusted so the seat was at a 21 degree ejection angle with respect to the floor. This is the angle between the ejection line and the heel rest line in the F-14. The F-18 mock-up rudder pedals were located as they would be in an F-14.

A styrofoam replica of the ACM panel and center console were constructed and fastened to the cockpit floor. The ACM panel position with respect to the ejection angle was located according to F-14 drawing no. A51F00205. Critical dimensions to the mock-up ACM panel with respect to the seat and floor were verified before each test. A photo of the tower set-up is shown in Figure 6.

EJECTION SEAT

A Martin Baker SJU-5/A seat as used in the F-18 aircraft was selected for these tests. Although the F-14 aircraft uses a Martin Baker MK GRU-7A seat, the sitting platforms of the two seats are sufficiently alike to gather data on lower leg and foot travel past the mock-up ACM panel. Leg restraints were not used during these tests since they were not included on the F-18 tests and it was not practical to install leg restraints for these tests. In the opinion of Engineering the lack of leg restraints does not affect the results of this study since the leg restraint system does not retract the legs but holds them against the seat after catapult separation. The legs are naturally retracted during the application of seat acceleration. The seat is still under this acceleration at the time they pass the mock-up ACM panel. The catapult force during the first 40 inches of seat travel was replicated on the ejection tower. Figure 7 contains the acceleration-time histories for these three tests.

TEST SUBJECTS

Three volunteer human test subjects participated in this study. Anthropometric data for each of the subjects is shown in Table 1. Subjects were selected so their sizes varied to the maximum extent possible as limited by the size of the subject pool. During these tests the subjects wore a flight suit, boots, MA-2 torso harness, APH-6 helmet and a MBU-14/P oxygen mask.

As with any test program conducted by the Navy that involves the exposure of human subjects, stringent regulations were followed to ensure maximum safety for the subject. For this program a medical support team was on site before, during, and after each human subject test. The team was headed by a Medical Officer and included, as a minimum, a senior corpsman and two rated corpsmen. In addition, a ready ambulance was on site for each test, plus a portable defibrillator and other emergency medical supplies. Each subject was monitored for EKG response

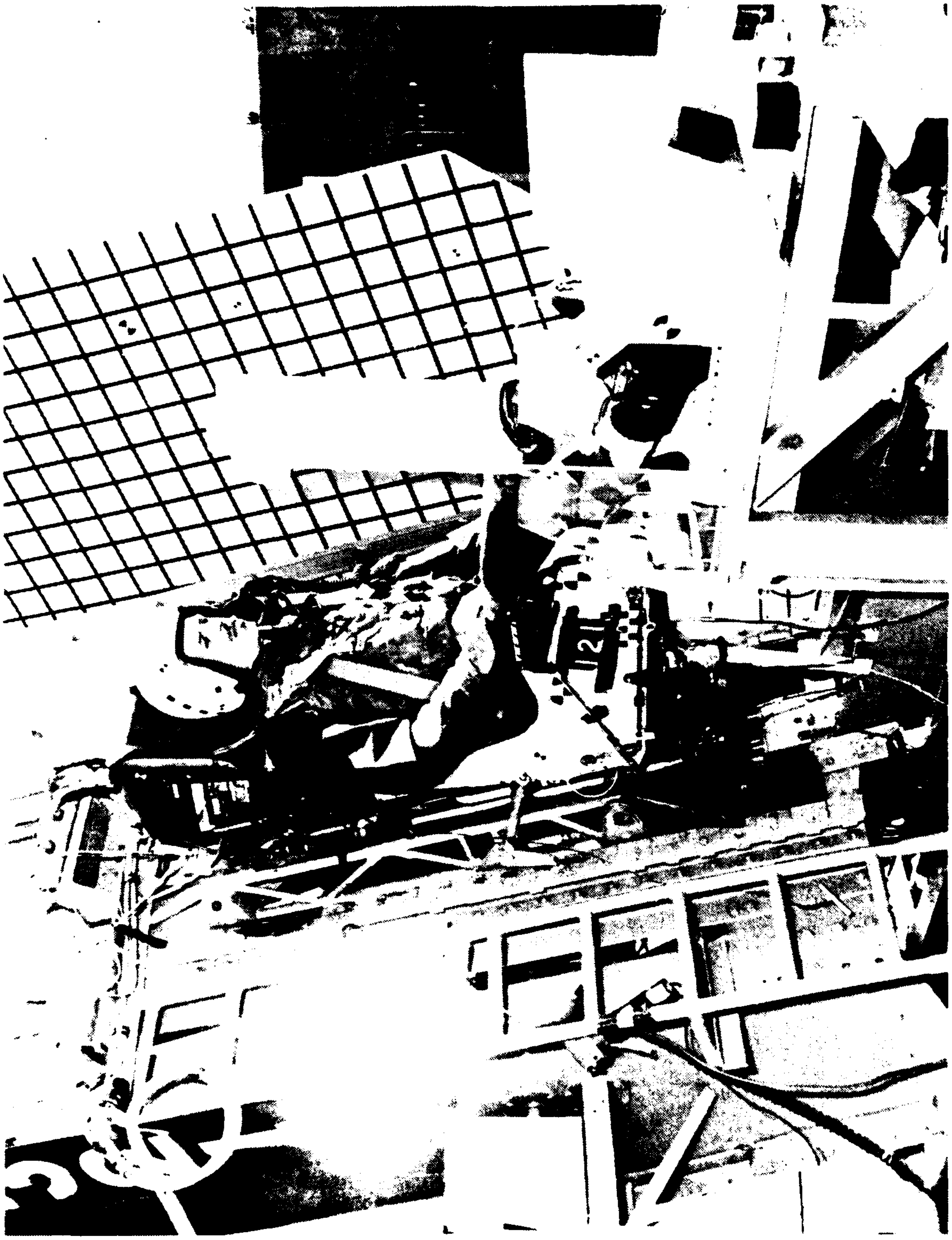

Figure 6. Ejection Tower Test Set-Up

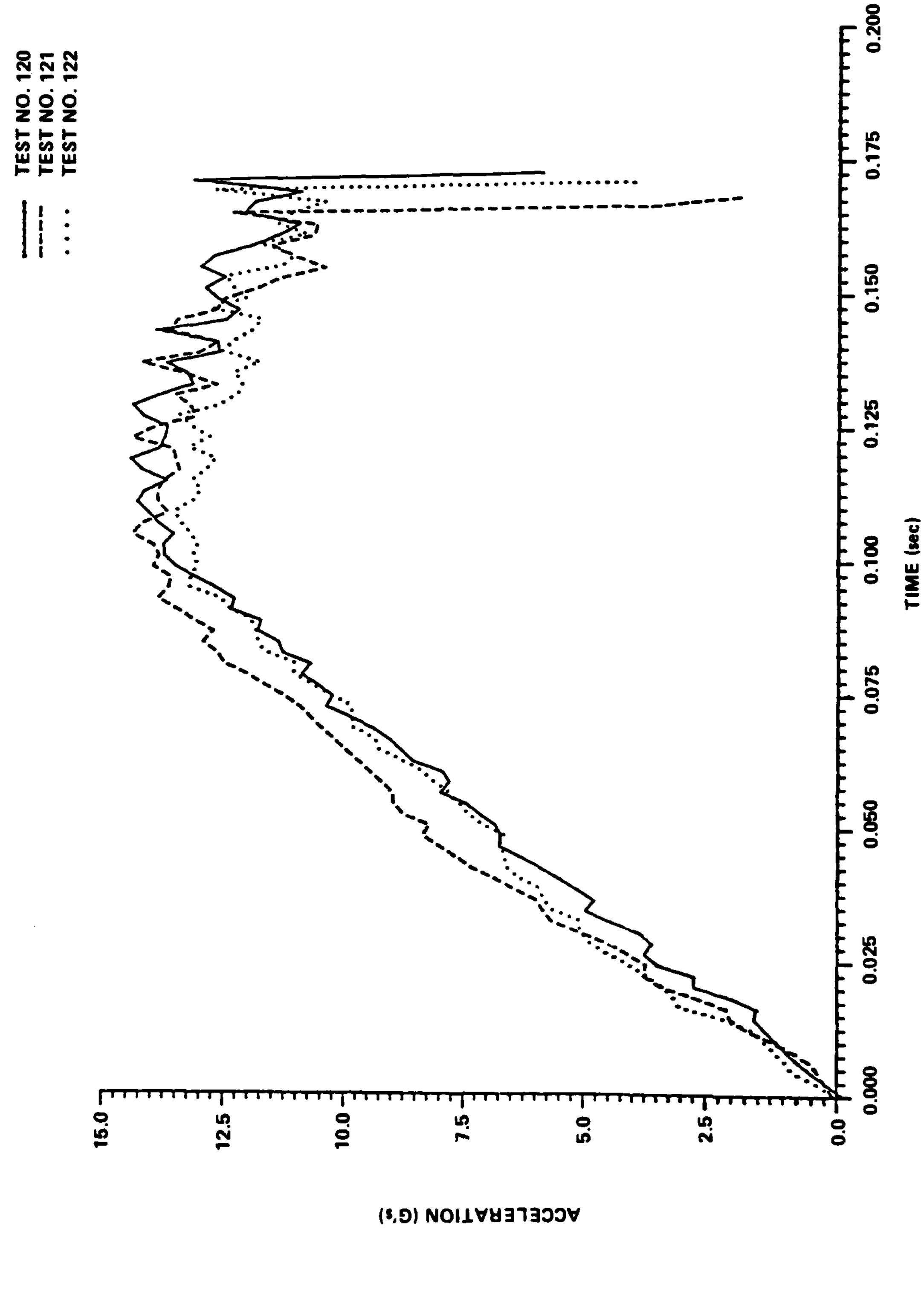

Figure 7. Vertical Seat Acceleration

Table 1. Anthropomorphic Data

1964 Navy Survey Percentiles Per Anthropometric Dimension of Subjects for F-14 Tower Program.

Note: Dimensions are in centimeters.

Test/Subject	Height		Sitting Height		Butt-Knee		Bidel. Diam.		Sitting Shoulder		Sitting Eye Ht.		Chest Width		Knee Ht.	
	dist. (cm)	per-cen-tile	dist. (cm)	per-cen-tile	dist. (cm)	per-cen-tile	dist. (cm)	per-cen-tile	dist. (cm)	per-cen-tile	dist. (cm)	per-cen-tile	dist. (cm)	per-cen-tile	dist. (cm)	per-cen-tile
120/A	174.4	31	96.3	90	54.1	-1	47.8	52	63.4	86	86.6	98	31.7	32	50.8	3
121/B	180.2	66	92.9	60	61.5	56	48.7	68	65.9	98	82.3	77	35.5	90	54.5	35
122/C	175.9	40	93.9	73	61.0	48	50.1	85	62.7	80	79.5	42	35.6	91	52.6	14

before, during, and after each test, and had direct communications with the Medical Officer and the test directors for an immediate report of physical condition.

DATA COLLECTION

ELECTRONIC INSTRUMENTATION

Electronic instrumentation data was recorded to confirm that proper seat accelerations were obtained and to correlate seat travel with photographic coverage. Table 2 lists the electronic instrumentation data obtained during these tests. All transducers were calibrated in accordance with standard NAVAIRDEVCEN procedures. The records are stored and available at NAVAIRDEVCEN.

PHOTOGRAPHIC COVERAGE

Table 3 lists the photographic cameras and their placement for the series of tests. Their purpose was to record subject body motion during each test for analysis. All films and photographs are stored and available at NAVAIRDEVCEN.

Table 2. Instrumentation Data Channels

	Range
1. Catapult pressure	0-2500 psi
2. Vert. catapult acc.	±50 G
3. Vert. seat acc.	±50 G
4. Strobe light sync.	N/A
5. Seat displacement	40 in.

TOWER TEST RESULTS

None of the three test subjects contacted the mock-up ACM panel. A detailed analysis of each subject's leg and foot travel was not conducted for this series of tests. This feasibility study was conducted to quickly identify whether relocation of the ACM panel posed an ejection hazard. The following observations about the lower leg and foot travel past the mock-up ACM panel were noted.

All three subjects exhibited similar lower leg and foot travel during the ejection stroke. Initial seat movement induces upward motion of the subject's lower legs and feet, which lift up, then rotate back to align below the knees. Near the end of the catapult stroke, which is approximately the point where the subject's toes pass the mock-up ACM panel, the lower legs were sufficiently retracted to clear the panel with their toes positioned downward in line with the ejected angle. After catapult separation the toes realign and point in toward the center line of the seat. Some differences in the three subjects lower leg and foot travel were noted. The speed and positioning of the lower leg and toes varied during retraction. The toes of subject A retracted aft of his knees while the toes of subject C were not fully retracted at catapult separation. The right toe of subject B pointed in during the ejection stroke and contacted the vertical support used to support the mock-up ACM panel. Figures 8 through 10 show each subject at catapult separation.

Table 3. Camera Information

Camera No.	Manufacturer	Film Speed (FPS)	Lens Size	Camera Location and Coverage
1	Photosonics	1000	13mm	Right Side of Tower First Foot of Seat Travel
2	Photosonics	1000	25mm	Right Side of Tower Last Foot of Seat Travel Before Separation
3	Photosonics	1000	25mm	Front of Tower Entire Ejection Stroke
4	Miliken	400	40mm	Front Right Side of Tower Tracking
5	Miliken	400	15mm	Right Side of Tower Entire Ejection Stroke
6	Miliken	400	25mm	Above the Seat Entire Ejection Stroke
7	Nikon	Single Frame	50mm	Right Side of Tower at 6 Inches of Seat Travel
8	Nikon	Single Frame	50mm	Right Side of Tower At Catapult Separation

Figure 8. Catapult Separation, Subject A

Figure 9. Catapult Separation, Subject B

Figure 10. Catapult Separation, Subject C

All three subjects had previously been exposed to tower ejections during the SJU-5/A Physiological Acceptance Tests. Although a mock-up ACM panel was not used and the rudder pedal configuration was not located as in an F-14, their lower leg and foot positions were noted at catapult separation (toe clips were installed for these tests). When these positions were compared with the F-14 configuration tests they were found to be almost identical. It should be noted that the right toe of subject B didn't point in during the ejection stroke on these tests.

The results of this feasibility study do not indicate that a problem exists with relocating the ACM panel. The lower extremities of all three subjects passed by the mock-up ACM panel without contact. However, these tests should not be interpreted as an endorsement or qualification of the safety aspects of relocating the ACM panel. The tests were preliminary in nature to identify gross problems. A more rigorous testing regimen must be conducted using a larger percentile population and appropriate test equipment before it can be ascertained that the relocation of the ACM panel does not present a safety threat to the ejectee.

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2. Miller K., "Physiological Acceptability Tests of the Modified SJU-5/A Ejection Seat for the F-F-18 Aircraft", Report No. NADC-84009-60, Jan. 1984, Naval Air Development Center, Warminster, PA.

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